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AMMRC AUTOMATED STRESS-STRAIN DATA ANALYSIS, STORAGE, AND RETRI--ETC(U)

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AMMRC AUTOMATED STRESS-STRAIN DATA ANALYSIS, STORAGE, AND RETRIEVAL - PART 1: DATA ANALYSIS PROGRAM

April 1979

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AMMRC TR 79-16 AMMRC AUTOMATED STRESS-STRAIN DATA ANALYSIS, STORAGE, AND RETRIEVAL - Papirno

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ABSTRACT

As part of an in-house effort to improve physical standards and tolerances for materiel through the improvement of acceptance/rejection criteria, we have developed a procedure for computer processing, storage, and retrieval of mechanical properties data. In this report, which is the first of a three-part series, a system for computer-assisted stress-strain test data reduction and analysis is described. Autographic recordings of load-strain data are semi-automatically digitized on a remote graphics terminal coupled to a UNIVAC 1106 computer. Descriptor data are also entered into temporary memory of the computer. The analysis includes a calculation of the Ramberg-Osgood exponent and yield stress from which the stress-strain curve of the test material can be readily reproduced. The output of the analysis program consists of several optional printouts for each set of test data and a punch card containing coded descriptor data and a summary of all the results for the test. The output punch cards serve as a hard copy data file of test results. The system has been applied to establish a file of tension test results.

The procedures for establishing a computer data file of the test results and for retrieving the data are described in AMMRC TR 79-17, and listings of the FORTRAN symbolic programs used for data reduction, analysis, storage, and retrieval are given in AMMRC TR 79-18.

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INTRODUCTION

As part of an in-house effort to improve physical standards and tolerances for materiel through improvement of acceptance/rejection criteria, we focussed on the role of mechanical properties of materials. While many hundreds of mechanical properties tests are conducted each year by the Materials Properties Branch (MPB) of the Engineering Standardization Division (ESD), there had been no systematic way in which the test results could be made generally available. Test reports were issued only to principal investigators who had ordered the tests while the raw data remained on file in the MPB.

Early in 1977 a program was initiated as a joint effort by ESD and the Engineering Mechanics Division (EMD) to make the on-file data readily retrievable to all AMMRC personnel. Such data would be of value to ESD in developing standards and tolerances. A first task was to develop computer-assisted methods for analyzing the data and for generating hard-copy output of the analyzed results. A second task was to establish a data bank of the results in the NARADCOM UNIVAC 1105 computer and to develop the software to access the data from either teletype or graphics demand terminals.

This report (Part 1) describes the analysis procedures which were developed and the various forms of hard-copy output which are now available. Included is a detailed description of a proposed computer-generated test report which is to be issued by MPB to principal investigators in lieu of the current manually prepared report of mechanical test results.

Part 2 (Reference 1) is devoted to descriptions of the computer data bank contents, of procedures for adding data, and of the forms of output available in the retrieval program. Also included in Part 2 are a set of user instructions for data retrieval.

Part 3 (Reference 2) contains complete FORTRAN listings for all the programs which have been developed for analysis, storage, and retrieval of test data.

It should be noted that all the data which have been analyzed and stored to date are from tension stress-strain tests. The computer programs, however, are appropriate for compression and shear tests as well. By far, tension results constitute the largest file of past test results, hence our first efforts were focussed in this area. Currently we have begun to analyze and store all tension test results starting with tests conducted in July 1977 and will continue until the data bank is up-to-date. Thereafter, the data bank will be maintained current and, as time allows, data from tests performed prior to July 1977 will be analyzed and stored.

Compression and shear stress-strain data will be analyzed and stored in the near future. Plans are now being made for computer-assisted data reduction and

1. **PAPIRNO, R. P.** *AMMRC Automated Stress-Strain Data Analysis, Storage, and Retrieval - Part 2: Data Bank Entry and Retrieval Procedures.* **Army Materials and Mechanics Research Center, AMMRC TR 79-17, April 1979.**
2. **PAPIRNO, R. P.** *AMMRC Automated Stress-Strain Data Analysis, Storage, and Retrieval - Part 3: Computer Program Listings.* **Army Materials and Mechanics Research Center, AMMRC TR 79-18, April 1979.**

analysis of fracture toughness and impact test results and for establishing a computer file of the analyzed data. Also in the planning stage are procedures for obtaining complete processing histories of test specimens and coding the materials uniquely according to chemistry, manufacturing procedures, and thermomechanical treatment. A data base of these well-characterized materials will then be established.

RAW DATA REDUCTION

Raw data from an MPB tension stress-strain test consist of the following:

1. Test descriptors, ultimate load, elongation, and reduction of area which are recorded in a tension test notebook. If a hardness test has been performed, the hardness data are recorded in a hardness test notebook and the tension notebook entry references the hardness data by notebook number and page.

2. An autographic recording of the test load versus strain to the approximate 0.2% offset yield stress or somewhat higher. The strain data are obtained from an extensometer attached to the specimen. The record may also contain data well beyond the yield from a deflectometer which senses testing machine head motion rather than specimen strain. Several tests may be recorded on a single graph sheet but in each case there is a notebook reference on the graph to relate the notebook data to the graph unambiguously.

Computer Processing

A computer-assisted data reduction program was written and filed in the NARADCOM UNIVAC 1106 machine for reducing the raw data. The program, called R*PICPTS is described in Reference 3 and listed in Reference 2. The procedure involves codifying the material and test descriptors, entering the descriptor data into temporary memory in the computer and digitizing the autographic load-strain curve at a computer graphics terminal. The hard-copy output is a deck of punch cards generated by the computer. The input procedure is performed interactively at a demand terminal in the MPB. The descriptor data are entered via the keyboard of a Tektronix 4014 graphics terminal in response to instructions which appear on the screen. The autographic record is digitized on a Tektronix 4662 interactive plotter which is coupled to the graphics terminal. The output cards are punched automatically by one of the UNIVAC 9300 hard-copy, input-out terminals.

Digitizing the Load-Strain Curve

Digitization of the load-strain curve is semiautomatic. Instructions for every step in the process appear on the screen of the graphics terminal. The operator controls the movement of the pen carriage of the plotter on which optical cross hairs have been substituted for the pen. As described in Reference 3, the location of the approximate proportional limit and 0.2% offset yield

3. **PAPIRNO, R. P.** ***PICPTS Computer Program for Digitizing Testing Machine Autographic Records: User Instructions.*** **Army Materials and Mechanics Research Center, AMMRC TN 78-6, June 1978.**

loads have been determined as part of the preparation procedure prior to the computer run. The operator digitizes approximately 10 equally spaced points between the curve-zero and the proportional limit and approximately 20 equally spaced (along the curve) points between the proportional limit and the yield loads. Thereafter, points are digitized for every 0.006 in./in. of strain until the end point of the curve. On curves with a sharp knee, the point spacing in the knee region is decreased so that the curve shape is better approximated by the digital values.

While it may appear that the process is time consuming, we have found that an operator with but a few hours of instruction and practice can completely process between three and four records an hour. About 75% of the total time is devoted to the digitizing process and the remainder to entering descriptor data. We have trained student aides to perform the entire data reduction process and have had great success in obtaining accurate results with only a minimum of professional supervision. The computer program was written so that specific step-by-step instructions appear on the screen of the terminal before each of the required entries is to be made.

Output

At present, the output of each run of the R*PICPTS program is a deck of punch cards. For each set of test data there is a header card containing descriptor data in 80 columns followed by digitized data cards each having one value of load and one value of strain. The data cards serve as input to an analysis program also on file in the UNIVAC 1106, which is called R*EVALRO. This program is described in detail in the next section of this report.

Card images of the output punch cards are also inserted into a temporary file in the computer. The operator of R*PICPTS program has the option of executing the R*EVALRO analysis program automatically at the conclusion of a data reduction run. For this option, the input to the analysis program consists of the card images in the temporary file. The output of the analysis program in this case is a test report, called the Principal Investigator Report. It is described in detail in the Analysis section of this report.

Applications

We had several specific applications for the output data of our data processing systems. The applications in turn influenced the choice of analysis computations and procedure and the form of output that were programmed. The following considerations were useful guides in program development:

1. To make the on-file data more readily available throughout AMMRC, we had planned to establish an easily accessible data bank of stress-strain properties. We decided that a user of the data bank should be able to retrieve all the test data for a given material/alloy including the stress-strain curve.

2. In order to improve the reporting procedures of the MPB, we planned to generate, using the computer, a stress-strain test report for principal investigators who submitted specimens for testing. This report would be one of the

outputs of the data processing program developed for the data bank and hence would require no extra effort. Such an arrangement would eliminate completely the manual preparation of test reports.

3. We wished to minimize storage requirements for the analyzed data in the computer. We also planned to keep a hard-copy backup for the data bank in the form of a file of punch cards. This led to developing coding schemes and other data condensation techniques such that all the analyzed data from a single test could be punched on one 80-column punch card.

STRESS-STRAIN DATA ANALYSIS

Structural applications of stress-strain data in computer-aided stress analysis and design require an analytic formulation of the stress-strain curve of materials. Examples where such a formulation would be used are studies of elastic-plastic buckling, elastic-plastic notch behavior, and finite element and finite difference calculations of elastic-plastic deformations. If data are to be stored economically, there are advantages in expressing a stress-strain curve in algebraic form since only a few equation constants need be stored rather than a set of digitized points of the curve.

While no completely satisfactory single algebraic formula has been developed to characterize a stress-strain curve of a material to fracture, the Ramberg-Osgood approximation has proved particularly useful and accurate for reproducing the stress-strain properties to the yield stress.* In the tests conducted by the MPB, high resolution strain data from extensometers was available to somewhat in excess of the yield, hence we decided to use the Ramberg-Osgood formula for storing the stress-strain curve.

Ramberg-Osgood Equation

Only three constants are required in the Ramberg-Osgood equation. One formulation of the equation which is very widely used is

$$e = S/E + 0.002\ (S/S_y)^n \tag{1}$$

where e and S are the strain and stress and the three required constants are:

E = elastic modulus,

S_y = 0.2% offset yield stress,

n = Ramberg-Osgood exponent.

Note that the nondimensional form of the stress terms in Eq. 1 makes the exponent independent of the system of units used for stress. Hence, metric conversion of the equation from the conventional English system of units (or vice versa) requires only arithmetic conversion of the modulus and yield stress factors.

*The stress-strain curves reproduced in MIL-HDBK-5 were all plotted using the Ramberg-Osgood equation derived from averaged stress-strain data. At AMMRC we analyzed several hundred sets of data and found that the correlation coefficient for the equation with respect to the test data was better than 0.98 in more than 92% of the stress-strain curves examined.

Calculations of the modulus, the yield stress, and exponent for Eq. 1 are made by the EVALRO program using least-squares procedures. As will subsequently be shown, the program also calculates the standard error of estimate and correlation coefficient which can be used to assess the goodness-of-fit of the Ramberg-Osgood equation to the experimental data.

Elastic Modulus Calculation

Specimen area and approximate proportional limit load are among the data which are read in to the EVALRO program from the PICPTS header card. The load-strain data are converted to stress-strain data using the area value. The program requires that the digitized data be ordered in increasing strain magnitude; if necessary, the program will order the data.

A linear least-squares analysis is performed using all the input data whose stress values are less than or equal to the input value of proportional limit. The result of this analysis is a value of the elastic modulus and the value of the strain intercept. The latter represents the intersection of the elastic line on the strain axis. (The best-fit elastic line will not always pass through the origin established in digitizing the load-strain data.) In order to assure that Eq. 1 will pass through the origin, the strain intercept value (generally of the order of tens of microinches/inch) is algebraically subtracted from all input strain values. We have called the resulting values "adjusted" strain to differentiate them from the originally digitized raw data values.

Yield Stress and Ramberg-Osgood Exponent Calculation

There are two components of strain explicit on the right-hand side of Eq. 1. The term S/E represents the elastic component of the total strain and the second term represents the plastic component:

$$e_p = 0.002\ (S/S_y)^n \tag{2}$$

where $e_p = e - (S/E)$.

It is desirable to rearrange Eq. 2 to the form

$$S = A\ e_p^{\ m} \tag{3a}$$

where $m = 1/n$ (3b)

$$A = S_y/(0.002)^m. \tag{3c}$$

Taking the logarithm of both sides of Eq. 3 results in

$$\log S = m \log e_p + \log A. \tag{4}$$

Equation 4 is linear in the variables log S and log e_p, and the quantities m and log A can be calculated using a linear least-squares procedure. Then both the Ramberg-Osgood exponent and the 0.2% offset yield stress can be calculated from Eqs. 3b and 3c.

Multiple Least-Squares Procedure

As a first step in the EVALRO program, plastic strains for the nonelastic data are calculated. Then data between the approximate proportional limit and the approximate yield stress are used in the least-squares analysis for Eq. 4, providing there are at least eight data points available. If there are fewer than eight data points, then data beyond the yield are used. (The approximate yield is located by finding the data point whose e_p value is closest to 0.002.)

Experience has shown that a better fit of the data to Eq. 4 may result if the low-value plastic strains are omitted in the calculation. A systematic procedure was developed and incorporated in the EVALRO program to perform a series of ten least-squares analyses in which trial values of n and S_y are calculated. In this scheme the first (i - 1) points are dropped for the i^{th} analysis. Then values of the standard error of estimate and correlation coefficient are calculated for each of the ten trial values of n and S_y. All the data between the proportional limit and the yield are used in the calculation. The set of trial values of n and S_y which result in the largest correlation coefficient are designated as the best-fit values. The best-fit values of n and S_y and the value of the standard error of estimate are among the data which are stored in the AMMRC data bank.

Statistical Analyses

Values of the standard error of estimate and correlation coefficient are calculated for six regions of the stress-strain curve. These data are part of the printout of the EVALRO program and indicate in detail how well the Ramberg-Osgood equation fits the test data. The boundary points of the regions are the proportional limit, the 0.2% offset yield, and the end point of the data. In addition, and intermediate boundary point between the proportional limit and the yield stress is established by identifying the median stress of the data between the aforementioned bounds. The intermediate point has been called the midpoint. The boundary points are shown schematically in Figure 1 together with the data used in the statistical calculations. In the listing below, SPL refers to the proportional limit, MPT refers to the midpoint stress, SY refers to the yield stress, and SN refers to the end point of the data. The data groups which are used in each of the numbered analyses are as follows (the numbered analyses correspond to the numbered regions in Figure 1):

1. Elastic data up to SPL
2. From SPL to MPT
3. From MPT to SY
4. From SPL to SY
5. From SPL to SN
6. From SY to SN.

Printed Output of EVALRO

There are a number of optional printed outputs of the data and the statistical quantities. Print options are in an integer code. When the program is run,

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illus-tables, AMCMS Code 728012.12

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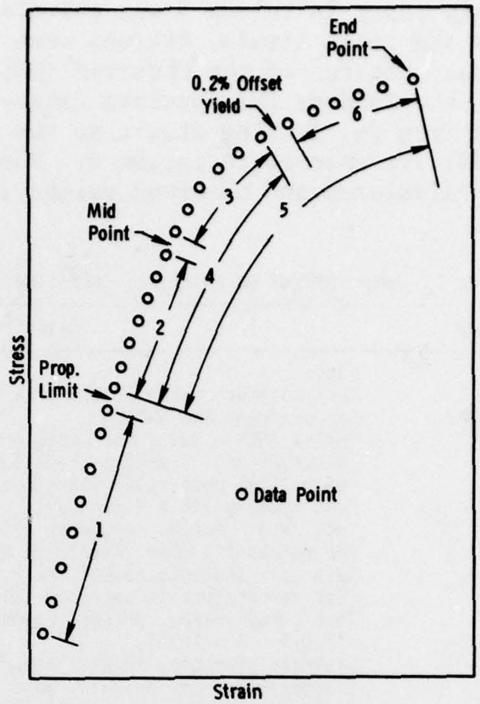

Figure 1. Regions of stress-strain curve for statistical analyses. The numbered regions correspond to the numbered analyses listed in the text (schematic).

the first data card contains the print option code digit (as well as data on the number of copies and whether punch-card output is required). The separate print-out options are described below.

1. *Principal Investigator Report.* A summary of the test and material descriptors, analyzed data, statistical data, and tabular listing of both the input digitized data and stress values calculated from the Ramberg-Osgood equation make up this printed output. Descriptor information is taken directly from the PICPTS program, transferred to the EVALRO program for printing and eventual storage. This output was designed to serve as a report of a stress-strain test, a copy of which is to be submitted to the principal investigator.

A sample of the test report is shown in Figure 2. The upper section is a summary of the test. Specific entries are explained on a line-by-line basis in Table 1.

A value of load and a value of strain are the raw data for every digitized point on the stress-strain curve. In the anlysis procedure previously described, the strains are adjusted so that the stress-strain curve passes through zero. In the tabular listing of data on the lower part of the sample report shown in Figure 2, the adjusted (ADJ) values of strain rather than the raw data values have been entered. Since the strain intercept was 5 microinches per inch (given on line 6 in the summary), the raw data were larger by this amount than the adjusted values given in column 3 of the tabular listing.

Each plastic strain entry in column 4 was calculated by subtracting the elastic component from the total strain. Values were rounded to the nearest 10 microinches per inch. Entries of the observed (OBS) stress in column 5 were calculated by dividing the load by the specimen cross-sectional area. Values of stress were calculated from Eq. 1 using strain as the independent variable and the values (CALC STRESS) are entered in column 6. The deviation in percent (DEV PCT) between the calculated and observed values is given in column 7.

Table 1. DATA CONTENT OF PRINCIPAL INVESTIGATOR REPORT

Line No.	Data Entry	Description
1	No data	Title
2	SPEC AREA	Test section cross-section area (0.0501).
3	SPECIMEN NO.	Six or fewer ANC (WTT-6).
3	MATERIAL	Twelve ANC in two 2 ANC coded groups and one 8 ANC abbreviated description. (Example ST-6A-4340 ESR) ST = Material code, 6A = Alloy code, 4340 ESR = Abbreviated uncoded description.
3	TEST TYPE	Test loading (TENS = tension).
3	DATE	Test date - month, day, year (100678).
3	NTBK-PG	MPB notebook number (1A67) and page (65).
3	SET NO	Data set catalogue number (867).
4	TEMP	Test temperature in degree C (20°).
4	EDOT	Test strain-rate, per-sec, rounded to nearest decade (1.0-4 = 1×10^{-4}).
4	S-ULT	Ultimate strength, in ksi (314.99) and MPa (2171.8).
4	ELONG	Elongation, 1-in. or 2-in. gage length, in percent (9.7).
4	RED-A	Reduction of area in percent (30.1).
4	R-CH	Rockwell C hardness (55.0). (If test not done, entry = -1.)
6	INCPT	Intercept of raw data stress-strain curve on strain axis. Value given in microinches per inch (5).
6	MODULUS	Least-squares value of elastic modulus in 10^6 psi (29.59).
6	SEE	Standard error of estimate of modulus in ksi (0.56).
6	C-CFT	Correlation coefficient of modulus (0.9999).
6	PTS	Number of elastic data points used to compute modulus (10).
6	EP-I	Lower limit plastic strain value used in R-O analysis for best-fit, in microinches per inch (185).
6	.2%-YLD	Calculated best-fit 0.2% offset yield strength for R-O equation in ksi (199.15). S_y value for Eq. 1.
6	EXPNT	Ramberg-Osgood exponent, n, for Eq. 1 (9.00).
6	PTS	Number of data points used in best-fit R-O analysis (11).
6	SPL	Calculated proportional limit using Eq. 1 for a class B extensometer (10 microinches per inch least count) in ksi (110.50).
6	.1%-YLD	Calculated 0.1% offset yield stress using Eq. 1 in ksi (184.38).
7	MODULUS	Value in GPa (204.0).
7	SEE	Value in MPa (3.9).
7	.2%-YLD	Value in MPa (1373.1).
7	SPL	Value in MPa (761.9).
7	.1%-YLD	Value in MPa (1271.2).
8-9	No data	
10	SEE	Standard error of estimate in ksi for regions 2-6 (0.82, 0.81, 0.81, 3.74, 6.26).
10	C-CFT	Correlation coefficient for regions 2-6 (0.9978, 0.9960, 0.9993, 0.9928, 0.6614).
10	PTS	Number of data points used in calculations for regions 2-6 (9, 8, 17, 26, 9).
11	SEE	Standard error of estimate in MPa for regions 2-6 (5.6, 5.6, 5.6, 25.8, 43.1).

NOTE: The information given in parentheses in the Description column is the entry for this item in the sample report shown in Figure 2. (ANC is the abbreviation for alphanumeric characters.)

It should be noted that calculation of stress from Eq. 1, when the strain is specified, involves solution of an equation of the form:

$$Z + AZ^n - B = 0 \tag{5}$$

where $Z = S/S_y$ and A and B are constants which can be calculated from the elastic modulus and specified strain values. The exponent n in Eq. 5 is the Ramberg-Osgood exponent. A subroutine of the EVALRO program uses a trial and error procedure to obtain a solution of the equation with an accuracy better than 0.01%. Solutions of the equation are also required in the calculation of the statistical parameters.

2. *Condensed Summary*. Information in the summary section of Figure 2, printed four data sets to the page, constitute a second printout option. An up-to-date file of the condensed summaries of all the data which have been processed is being maintained in this format. These data can readily be cross-referenced from entries in the data bank.

```
        **PRINCIPAL INVESTIGATOR REPORT ON STRESS-STRAIN TEST AND RAMBERG-OSGOOD ANALYSIS **
BEST-FIT MODULUS, 0.2% OFFSET-YIELD, AND R-O EXPONENT CALCULATED BY LEAST SQUARES. (SPEC AREA= .0501 SQ-IN)

 SPECIMEN NO: WTT-6   MATERIAL: ST-6A-4340 ESR  TEST TYPE: TENS   DATE: 100678  NTBK-PG: 1A67-65  SET NO:  867
 TEMP=   20C  EDOT=1.0-4 PER-SEC  S-ULT=  314.99 KSI ( 2171.8 MPA)  ELONG=  9.7%  RED-A= 30.1%  R-CH= 55.0

          UNITS : INCPT  MODULUS    SEE    C-CFT  PTS : EP-I  .2%-YLD   EXPNT  PTS :   SPL   .1%-YLD
          ENGL  :     5   29.59     .56    .9999   10 :  185   199.15    9.00   11 :  110.50  184.38
          METRC :         204.0     3.9               :        1373.1               :   761.9  1271.2

                SPL TO MPT        MPT TO SY          SPL TO SY          SPL TO SN          SY TO SN
               SEE  C-CFT PTS   SEE  C-CFT PTS    SEE  C-CFT PTS    SEE  C-CFT PTS    SEE  C-CFT PTS
      ENGL     .82  .9978   9   .81  .9968   8    .81  .9993  17   3.74  .9928  26   6.26  .6614   9
      METRC    5.6              5.6               5.6              25.8              43.1
---------------------------------------------------------------------------------------------------------
   ** UNITS: MODULUS IN M-PSI OR GPA * .2%-YLD, .1%-YLD, SPL & SEE IN KSI OR MPA * INTCPT AND EP-I IN MICRO-IN/IN **
---------------------------------------------------------------------------------------------------------

      SPEC NO: WTT-6   *DIGITIZED STRESS AND STRAIN VALUES AND THEORETICAL STRESS AND STRESS DEVIATIONS*
 ANALYTIC DATA CALCULATED USING BEST-FIT RAMBERG-OSGOOD PARAMETERS: SY= 199.15 KSI, N=   9.00 & E= 29.59 M-PSI
```

PT NO	LOAD LBS	ADJ STRAIN IN/IN	PLASTIC STRAIN MU-EPS	OBS STRESS KSI	CALC STRESS KSI	DEV PCT	PT NO	LOAD LBS	ADJ STRAIN IN/IN	PLASTIC STRAIN MU-EPS	OBS STRESS KSI	CALC STRESS KSI	DEV PCT
1	617.	.00039	0	12.32	11.66	-5.3	31	10714.	.01020	2977	213.85	209.32	-2.1
2	1172.	.00078	0	23.39	23.20	-.8	32	10881.	.01059	3255	217.19	211.57	-2.6
3	1789.	.00119	0	35.71	35.34	-1.0	33	11048.	.01103	3582	220.52	213.92	-3.0
4	2352.	.00163	0	46.95	48.36	3.0	34	11216.	.01142	3859	223.87	215.87	-3.6
5	2960.	.00201	0	59.08	59.61	.9	35	11322.	.01181	4177	225.99	217.71	-3.7
6	3604.	.00243	0	71.94	72.04	.1	36	11498.	.01221	4459	229.50	219.50	-4.4
7	4220.	.00284	0	84.23	84.17	-.1							
8	4758.	.00319	0	94.97	94.53	-.5							
9	5374.	.00361	0	107.27	106.96	-.3							
10	5982.	.00403	0	119.40	119.39	-.0							
11	6396.	.00431	0	127.66	126.66	-.8							
12	6608.	.00447	17	131.90	131.04	-.7							
13	6802.	.00462	36	135.77	135.05	-.5							
14	7048.	.00481	60	140.68	139.99	-.5							
15	7382.	.00506	84	147.37	146.20	-.8							
16	7621.	.00527	134	152.12	151.13	-.6							
17	7797.	.00544	185	155.63	154.93	-.5							
18	8009.	.00569	292	159.86	160.17	.2							
19	8239.	.00594	387	164.43	165.01	.4							
20	8520.	.00622	477	170.06	169.97	-.1							
21	8722.	.00652	641	174.09	174.78	.4							
22	8952.	.00683	796	178.68	179.27	.3							
23	9185.	.00718	986	183.41	183.82	.2							
24	9392.	.00755	1219	187.47	188.11	.3							
25	9639.	.00797	1473	192.40	192.46	.0							
26	9868.	.00829	1638	196.97	195.45	-.8							
27	10026.	.00869	1932	200.12	198.86	-.6							
28	10220.	.00906	2171	203.99	201.76	-1.1							
29	10361.	.00938	2396	206.81	204.07	-1.3							
30	10529.	.00978	2682	210.16	206.73	-1.6							

Figure 2. EVALRO Principal Investigator Report. The entries in the upper data summary are defined in Table 1. The lower tabular listing is described in the text.

3. *Multiple Regression Summary.* When the EVALRO program was being developed, it was of interest to determine whether the multiple regression analyses used to determine a best-fit set of Ramberg-Osgood parameters (exponent and yield stress) were necessary. A third optional printout was provided in the program in which the results of all ten least-squares analyses were printed together with the statistical data. A sample printout is shown in Figure 3. A fourth optional printout is an adjunct of option 3. In this option, tables listing the input data and point-by-point predicted stress values and stress deviations are given for each of the ten analyses together with the material of option 3. A sample of the tabular printout is given in Figure 4. The third and fourth optional printouts have been described simply for documentation. These have not been used recently since they served their purpose early in the EVALRO program development to indicate that multiple regression and the associated statistical evaluation was a valid method to determine the best-fit Ramberg-Osgood exponent and 0.2% offset yield stress.

Punch Card Output of EVALRO

One major objective of the automated analysis program was to establish a file of test results for each tension test performed in the MPB. The individual entry to the hard-copy form of the file is a punch card, automatically punched by the computer, which summarizes the results of each test. Card images have also been entered into memory in the computer to form a data bank of test results and the data are retrievable from a variety of demand terminals served by the UNIVAC 1106 machine. In this report, the focus is on the data which appear on the EVALRO output card. In a subsequent report the entry and retrieval procedures for the computer data bank will be described (see Reference 2).

ANALYTIC APPROXIMATION OF STRESS-STRAIN PROPERTIES
RAMBERG-OSGOOD PARAMETERS OBTAINED FROM ANALYSES OF EXPERIMENTAL DATA

VALUES OF 0.2-PCT OFFSET-YIELD AND R-O EXPONENT FROM LOG-LEAST SQUARES CALCULATIONS

SPECIMEN NO: WTT-6 MATERIAL: ST-6A-4340 ESR TEST TYPE: TENS DATE: 100678 NTBK-PG: 1A67-65 SET NO: 867
TEMP= 20C EDOT=1.0-4 PER-SEC S-ULT= 314.99 KSI (2171.8 MPA) ELONG= 9.7% RED-A= 30.1% R-CH= 55.0

***** ELASTIC PROPERTIES *****

E= 29.59 MEGA-PSI S-INT= -175. PSI E-INT= 5 MU-IN/IN SEE= .56 KSI C-CFT= .9999 NO. DATA POINTS= 10
E= 204.0 GPA S-INT= -1.20 MPA SEE= 3.9 MPA

***** PLASTIC PARAMETERS *****

	ANAL NO.	INIT-EPS MU-STRAIN	R-O EXPNT N	.2%-YIELD KSI	.2%-YIELD MPA	PROP-LIM KSI	PROP-LIM MPA	.1%-YIELD KSI	.1%-YIELD MPA	ANAL PTS.	
	1	60	10.14	197.23	1359.9	116.97	806.5	184.20	1270.0	14	
	2	84	10.01	197.45	1361.4	116.33	802.0	184.25	1270.3	13	
	3	134	9.48	198.34	1367.5	113.45	782.2	184.36	1271.1	12	
**	4	165	9.00	199.15	1373.1	110.50	761.9	184.38	1271.2	11	BEST-FIT
	5	292	8.45	200.06	1379.3	106.86	736.8	184.30	1270.7	10	
	6	387	8.34	200.21	1380.4	106.08	731.4	184.25	1270.3	9	
	7	477	8.35	200.20	1380.3	106.16	732.0	184.26	1270.4	8	
	8	641	7.71	201.14	1386.8	101.20	697.8	183.86	1267.6	8	
	9	796	7.46	201.43	1388.8	99.00	682.6	183.55	1265.6	8	
	10	986	7.20	201.57	1389.8	96.52	665.5	183.06	1262.2	8	

***** STATISTICAL PARAMETERS *****

ANAL	INIT	SPL TO MPT SEE				MPT TO SY SEE				SPL TO SY SEE				SPL TO SN SEE				SY TO SN SEE			
NO	EPS	KSI	MPA	C-C R	NO PTS	KSI	MPA	C-C R	NO PTS	KSI	MPA	C-C R	NO PTS	KSI	MPA	C-C R	NO PTS	KSI	MPA	C-C R	NO PTS
1	60	.67	4.6	.9985	9	1.45	10.0	.9897	8	1.10	7.6	.9988	17	5.47	37.7	.9846	26	9.17	63.2	.0000	9
2	84	.66	4.5	.9985	9	1.37	9.4	.9908	8	1.05	7.3	.9989	17	5.28	36.4	.9856	26	8.85	61.0	.0000	9
3	134	.68	4.7	.9984	9	1.06	7.3	.9944	8	.88	6.1	.9992	17	4.48	30.9	.9897	26	7.51	51.8	.4353	9
4	185	.82	5.6	.9978	9	.81	5.6	.9968	8	.81	5.6	.9993	17	3.74	25.8	.9928	26	6.26	43.1	.6614	9
5	292	1.10	7.6	.9959	9	.60	4.1	.9982	8	.90	6.2	.9992	17	2.91	20.1	.9956	26	4.80	33.1	.8181	9
6	387	1.17	8.1	.9954	9	.57	3.9	.9984	8	.94	6.5	.9991	17	2.77	19.1	.9961	26	4.52	31.2	.8403	9
7	477	1.16	8.0	.9954	9	.57	4.0	.9984	8	.93	6.4	.9991	17	2.78	19.2	.9960	26	4.55	31.4	.8379	9
8	641	1.67	11.5	.9906	9	.59	4.1	.9983	8	1.28	8.8	.9984	17	1.97	13.6	.9980	26	2.86	19.7	.9395	9
9	796	1.92	13.3	.9874	9	.69	4.7	.9977	8	1.48	10.2	.9979	17	1.78	12.2	.9984	26	2.23	15.4	.9635	9
10	986	2.23	15.4	.9830	9	.86	5.9	.9964	8	1.73	11.9	.9971	17	1.71	11.8	.9985	26	1.68	11.6	.9796	9

Figure 3. EVALRO multiple regression analysis data summary.

SPEC. WTT-6 POINT-BY-POINT DEVIATIONS OF CALCULATED STRESSES FROM OBSERVED VALUES USING THE PARAMETERS FOR J=1 TO J=5

PT NO	ADJ STRAIN IN/IN	OBS STRESS KSI	PLASTIC STRAIN MU-EPS	60 MU-EPS-I STRESS KSI	60 MU-EPS-I DEV PCT	84 MU-EPS-I STRESS KSI	84 MU-EPS-I DEV PCT	134 MU-EPS-I STRESS KSI	134 MU-EPS-I DEV PCT	185 MU-EPS-I STRESS KSI	185 MU-EPS-I DEV PCT	292 MU-EPS-I STRESS KSI	292 MU-EPS-I DEV PCT
11	.004314	127.66	0	126.99	-.5	126.96	-.6	126.82	-.7	126.66	-.8	126.45	-1.0
12	.004474	131.90	17	131.44	-.3	131.40	-.4	131.23	-.5	131.04	-.7	130.78	-.8
13	.004624	135.77	36	135.53	-.2	135.49	-.2	135.28	-.4	135.05	-.5	134.75	-.8
14	.004814	140.68	60	140.56	-.1	140.51	-.1	140.26	-.3	139.99	-.5	139.63	-.7
15	.005064	147.37	84	146.89	-.3	146.82	-.4	146.52	-.6	146.20	-.8	145.78	-1.1
16	.005274	152.12	134	151.90	-.1	151.82	-.2	151.49	-.4	151.13	-.6	150.68	-.9
17	.005444	155.63	185	155.72	.1	155.65	.0	155.30	-.2	154.93	-.5	154.46	-.8
18	.005694	159.86	292	160.97	.7	160.90	.6	160.54	.4	160.17	.2	159.69	-.1
19	.005944	164.43	387	165.76	.8	165.69	.8	165.36	.6	165.01	.4	164.55	.1
20	.006224	170.06	477	170.60	.3	170.55	.3	170.28	.1	169.97	-.1	169.56	-.3
21	.006524	174.09	641	175.24	.7	175.20	.6	175.01	.5	174.78	.4	174.46	.2
22	.006834	178.68	796	179.49	.5	179.48	.4	179.40	.4	179.27	.3	179.06	.2
23	.007184	183.41	986	183.75	.2	183.77	.2	183.82	.2	183.82	.2	183.75	.2
24	.007554	187.47	1219	187.72	.1	187.77	.2	187.98	.3	188.11	.3	188.21	.4
25	.007974	192.40	1473	191.68	-.4	191.78	-.3	192.16	-.1	192.46	.0	192.76	.2
26	.008294	196.97	1638	194.39	-1.3	194.52	-1.2	195.02	-1.0	195.45	-.8	195.90	-.5
27	.008694	200.12	1932	197.45	-1.3	197.63	-1.2	198.28	-.9	198.86	-.6	199.50	-.3
28	.009064	203.99	2171	200.03	-1.9	200.22	-1.9	201.04	-1.4	201.76	-1.1	202.56	-.7
29	.009384	206.81	2396	202.06	-2.3	202.31	-2.2	203.22	-1.7	204.07	-1.3	205.00	-.9
30	.009784	210.16	2682	204.43	-2.7	204.70	-2.6	205.76	-2.1	206.73	-1.6	207.86	-1.1
31	.010204	213.85	2977	206.72	-3.3	207.01	-3.2	208.22	-2.6	209.32	-2.1	210.62	-1.5
32	.010594	217.19	3255	208.69	-3.9	209.00	-3.8	210.32	-3.2	211.57	-2.6	213.00	-1.9
33	.011034	220.52	3582	210.74	-4.4	211.10	-4.3	212.54	-3.6	213.92	-3.0	215.52	-2.3
34	.011424	223.87	3859	212.44	-5.1	212.81	-4.9	214.39	-4.2	215.87	-3.6	217.62	-2.8
35	.011814	225.99	4177	214.04	-5.3	214.43	-5.1	216.11	-4.4	217.71	-3.7	219.60	-2.8
36	.012214	229.50	4459	215.59	-6.1	216.01	-5.9	217.80	-5.1	219.50	-4.4	221.52	-3.5

Figure 4a. Tabular data associated with the results of the first five analyses given in Figure 3. The stress value in the column OBS STRESS is the LOAD/AREA value; the values in the other columns were computed using the Ramberg-Osgood equation. (Table continued in Figure 4b).

SPEC. WTT-6 POINT-BY-POINT DEVIATIONS OF CALCULATED STRESSES FROM OBSERVED VALUES USING THE PARAMETERS FOR J=6 TO J=10

PT NO	ADJ STRAIN IN/IN	OBS STRESS KSI	PLASTIC STRAIN MU-EPS	387 MU-EPS-I STRESS KSI	387 MU-EPS-I DEV PCT	477 MU-EPS-I STRESS KSI	477 MU-EPS-I DEV PCT	641 MU-EPS-I STRESS KSI	641 MU-EPS-I DEV PCT	796 MU-EPS-I STRESS KSI	796 MU-EPS-I DEV PCT	986 MU-EPS-I STRESS KSI	986 MU-EPS-I DEV PCT
11	.004314	127.66	0	126.40	-1.0	126.40	-1.0	126.06	-1.3	125.90	-1.4	125.69	-1.5
12	.004474	131.90	17	130.72	-.9	130.72	-.9	130.33	-1.2	130.13	-1.3	129.90	-1.5
13	.004624	135.77	36	134.68	-.8	134.69	-.8	134.23	-1.1	134.01	-1.3	133.75	-1.5
14	.004814	140.68	60	139.55	-.8	139.56	-.8	139.04	-1.2	138.79	-1.3	138.49	-1.6
15	.005064	147.37	84	145.69	-1.1	145.70	-1.1	145.10	-1.5	144.82	-1.7	144.48	-2.0
16	.005274	152.12	134	150.58	-1.0	150.60	-1.0	149.94	-1.4	149.64	-1.6	149.27	-1.9
17	.005444	155.63	185	154.35	-.8	154.37	-.8	153.69	-1.2	153.37	-1.5	152.98	-1.7
13	.003694	159.86	292	159.59	-.2	159.60	-.2	158.90	-.6	158.58	-.8	158.17	-1.1
19	.005944	164.43	387	164.45	.0	164.46	.0	163.78	-.4	163.45	-.6	163.05	-.8
20	.006224	170.06	477	169.47	-.3	169.48	-.3	168.85	-.7	168.54	-.9	168.14	-1.1
21	.006524	174.09	641	174.38	.2	174.39	.2	173.85	-.1	173.57	-.3	173.21	-.5
22	.006834	178.68	796	179.00	.2	179.01	.2	178.59	-.0	178.36	-.2	178.03	-.4
23	.007184	183.41	986	183.72	.2	183.72	.2	183.48	.0	183.31	-.1	183.04	-.2
24	.007554	187.47	1219	188.21	.4	188.21	.4	188.17	.4	188.07	.3	187.88	.2
25	.007974	192.40	1473	192.79	.2	192.79	.2	192.98	.3	192.99	.3	192.88	.3
26	.008294	196.97	1638	195.96	-.5	195.96	-.5	196.34	-.3	196.42	-.3	196.39	-.3
27	.008694	200.12	1932	199.60	-.3	199.59	-.3	200.20	.0	200.38	.1	200.45	.2
28	.009064	203.99	2171	202.69	-.6	202.68	-.6	203.52	-.2	203.77	-.1	203.93	-.0
29	.009384	206.81	2396	205.18	-.8	205.16	-.8	206.17	-.3	206.51	-.1	206.74	-.0
30	.009784	210.16	2682	208.06	-1.0	208.03	-1.0	209.27	-.4	209.69	-.2	210.04	-.1
31	.010204	213.85	2977	210.86	-1.4	210.83	-1.4	212.28	-.7	212.81	-.5	213.25	-.3
32	.010594	217.19	3255	213.28	-1.8	213.25	-1.8	214.92	-1.0	215.53	-.8	216.05	-.5
33	.011034	220.52	3582	215.83	-2.1	215.79	-2.1	217.70	-1.3	218.39	-1.0	219.03	-.7
34	.011424	223.87	3859	217.95	-2.6	217.92	-2.7	219.99	-1.7	220.79	-1.4	221.51	-1.1
35	.011814	225.99	4177	219.95	-2.7	219.92	-2.7	222.18	-1.7	223.04	-1.3	223.85	-.9
36	.012214	229.50	4459	221.91	-3.3	221.86	-3.3	224.31	-2.3	225.26	-1.8	226.15	-1.5

Figure 4b. Continuation of table in Figure 4a using the results of the last five analyses given in Figure 3.

Punch card output is an option which can be invoked with any of the printout options discussed above by an entry on the first input data card to EVALRO (on which the print option code also is punched). All the pertinent test results, descriptor information, and analyzed data are punched in the 80 columns. The stress-strain curve can be reproduced from the data on the card because the Ramberg-Osgood parameters are included. A listing of the EVALRO output card data is given in Table 2. The FORTRAN format for each entry is also given in the table.

Table 2. EVALRO OUTPUT PUNCH CARD DATA

Column	Entry	Format
1-6	Specimen number	A6
7-8	Material code	A2
9-10	Alloy code	A2
11-14	MPB notebook number	A4
15-16	Notebook page	I2
17	Test type code	I1
18-23	Test date	I6
24-28	Test temperature, deg C	I5
29-30	Log of strain rate	I2
31-36	Ultimate strength, ksi	F6.1
37-40	Elongation, pct	F4.1
41-44	Reduction of area, pct	F4.1
45-48	Rockwell C hardness	F6.2
49-54	Elastic modulus, mega psi	F6.2
55-61	R-O exponent	F7.2
62-68	0.2% offset yield strength, ksi	F7.2
69-72	R-O standard error, ksi	F4.1
73-76	Locater number	I-4
77-80	Set number	I4

All the data that appear on the card, with the exception of the entry in columns 73-76, are part of the printout of the program as described in Table 1 and shown in Figures 2 and 3. The standard error of estimate, punched in columns 69-72, is the value for Region 4 of Figure 1: for the data from the proportional limit to the yield stress referred to the best-fit Ramberg-Osgood exponent and 0.2% offset yield stress. The locater number in columns 73-76 is used in data retrieval. Specifically, it is the set number of the next earlier entry in the data file for a test of the same material and alloy. The number is assigned in a routine of the EVALRO program after reference to the computer-stored files. Additional details of the data management process are given in Reference 2.

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